

A new genus of Cretaceous margaritine gastropod (Turbinidae) from the northeastern Pacific Ocean

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ABSTRACT

Igonoia, a new genus of a margaritine vetigastropod, is recognized from Lower and Upper Cretaceous rocks in the northeastern Pacific, in the region extending from Vancouver Island, British Columbia, to southern California. Eight species are known, five are new; the early late Albian *I. kieli* new species and *I. shastana* new species; the late Cenomanian *I. onoensis* new species and *I. stewarti* (Murphy and Rodda, 1960) new combination; the late Turonian *I. vacca* new species; the Santonian *I. occidentalis* (Whiteaves, 1903) new combination; and the Maastrichtian *I. angulata* (Gabb, 1869) new combination and *I. muiri* new species. *Igonoia* is presently known to be endemic to the study area. Specimens are found predominantly in northern California, in fine-grained siliciclastic sandstones that were deposited in warm-temperate, shallow-marine waters. Specimens are most numerous in Santonian rocks.

Additional keywords: Mollusca, Margaritinae, fossil, endemic, temperate waters

INTRODUCTION

Small trochiform vetigastropods present in Cretaceous shallow-marine rocks of the northeastern Pacific are poorly documented in the literature. In the author's ongoing process of attempting to establish which genera are present, a new genus of margaritine vetigastropod was detected in museum collections. The new genus *Igonoia* occurs in both Lower and Upper Cretaceous shallow-marine rocks in the region extending from Vancouver Island, British Columbia, Canada to southern California. Specimens are locally abundant but are otherwise uncommon faunal elements. There are eight known species of the new genus, and five of them are new. The three previously named ones were originally

assigned to other similar-looking genera. In addition to erecting the new genus, the main purposes of this paper are to describe its species and to record their biostratigraphic succession. The areas where the specimens were collected are shown on Figure 1, and their designations (e.g., Area 3) are used throughout the paper. The details of the type localities of the species are given in the Appendix. The temporal distributions of the species are shown in Figure 2. Paleogeographic and paleoclimatic conditions of the new genus are discussed.

Included in this paper are supplementary descriptions (based on new examination of type material) and refined biostratigraphic records of the three previously named species: *Igonoia angulata* (Gabb, 1869); *Igonoia occidentalis* (Whiteaves, 1903); and *I. stewarti* (Murphy and Rodda, 1960). New information about the type locality of *I. angulata* is provided, and its type material consists of two species: *I. angulata* and *I. muiri* new species. The first photographic views of the type material of *I. occidentalis* are provided. Additional photographic views of *I. stewarti* are given, and its type material consists of two species: *I. stewarti* and *I. ononensis* new species.

This study was based on 260 specimens borrowed from museums having extensive collections of northeast Pacific Cretaceous fossils. Most of the specimens are stored in the Invertebrate Paleontology Collection at the Natural History Museum of Los Angeles County. The base and umbilical areas of the specimens are commonly encased in well-cemented, fine-grained siliciclastic sandstone. In order to remove this material, it was necessary to use a high-speed drill and diamond-coated grinding wheels, followed by the careful use of hand-held, very sharp needles. Preservation of shell material is generally good. Protoconch and early teleoconch whorls are very rarely present, and mostly or completely decollated. The one moderately well preserved protoconch with its shell intact was sputter-coated

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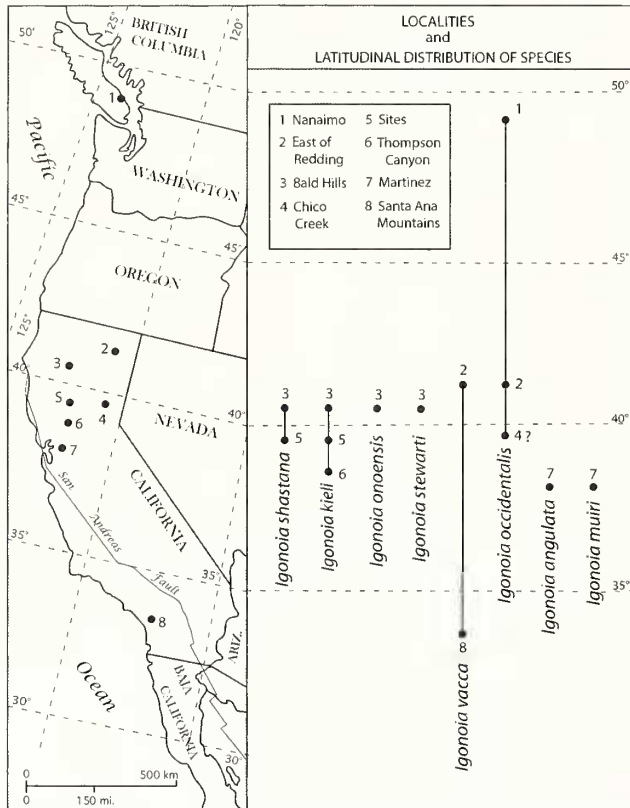


Figure 1. Localities map and latitudinal distribution of study area species of *Igonioia*.

prior to being imaged by means of an Hitachi S-3000N SEM (scanning electron microscope).

Abbreviations used for catalog and locality numbers are: ANSP: Academy of Natural Sciences, Philadelphia; GSC: Geological Survey of Canada, Ottawa; LACMIP: Natural History Museum of Los Angeles County, Invertebrate Paleontology; UCLA: University of California, Los Angeles (collections now housed at LACMIP); USGS: United States Geological Survey, Menlo Park, California (collections now housed at University of California, Berkeley, Museum of Paleontology).

SYSTEMATIC PALEONTOLOGY

Clade Vetigastropoda Salvini-Plawen, 1980
 Family Turbinidae Rafinesque, 1815
 Subfamily Margaritinae Stoliczka, 1868

Remarks: This subfamily was previously generally believed to be a trochid subfamily (e.g., Fretter and Graham, 1977; Hickman and McLean, 1990), but, based on molecular studies of extant taxa by Williams et al. (2008), it has been recently and provisionally recognized to be a turbinid. Williams et al. (2009) demonstrated that Margaritinae is not monophyletic.

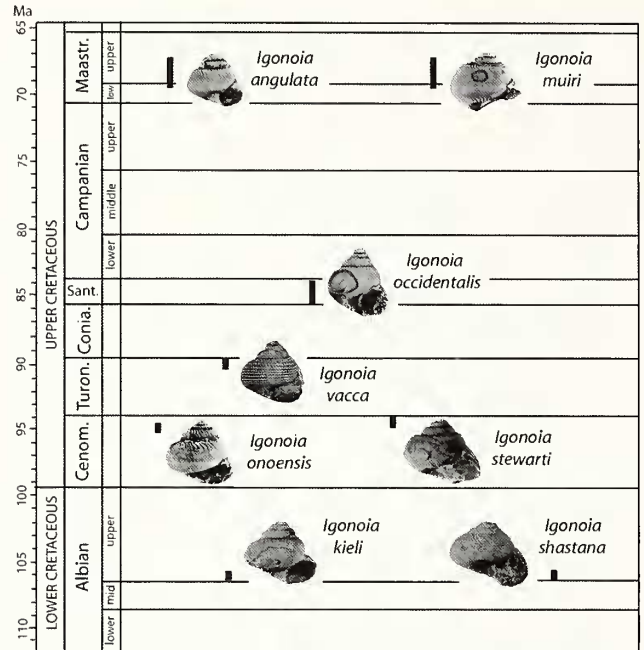


Figure 2. Geologic ranges of the studied species of *Igonioia*. Ages of stage boundaries from Gradstein et al. (2004).

Genus *Igonioia* new genus

Type Species: *Igonioia onoensis* new species, late Cenomanian, northern California.

Description: Shell size very small to medium small (4.5 to 13 mm height). Shell height commonly slightly less or approximately same size as shell diameter, rarely greater than diameter. Trochiform. Phaneromphalous. Spire low to moderately high, 43% to 59% of shell height. Pleural angle 80° to 95°. Protoconch smooth (most likely less than one whorl), transition to teleoconch unclear. First teleoconch whorl showing spiral threads before showing any axial ribs. Teleoconch four to six convex whorls; base usually rounded. Suture sunken and commonly groove-like. Teleoconch ornament of spiral ribs (beaded or unbeaded), commonly crossed by raised growth lines, especially on ramp/shoulder areas; shells can be nearly smooth. Shoulder rounded. Aperture circular. Peristome discontinuous. Last whorl large, base convex or keeled. Umbilicus open and deep, bounded by beaded weak to moderately strong spiral rib; umbilical wall can have cancellate ornament where growth lines intersect spiral ribs.

Geologic Age: Early late Albian to “mid” Maastrichtian (early late to late middle).

Etymology: Named for the adjacent towns of Igo and Ono in the Bald Hills area, Shasta County, northern California.

Remarks: After careful examination of each specimen, only two were found with remnants of their protoconch

present. Only one of these, a specimen of *I. onoensis* (Figures 21–22), has the shell intact on its protoconch, whereas the other, a specimen of *I. shastana* (Figure 14), is missing its shell on the protoconch and adjacent early teleoconch whorls (only an internal mold is present).

Gabb (1869) originally assigned the material that is now known to comprise *I. angulata* (Gabb, 1869) and *I. muiri* new species to genus *Margaritella* Meek and Hayden, 1860, a *nomen dubium* (not *Margaritella* Thiele, 1891).

The other previously named species of *Igonoia* were assigned eventually by other workers (Whiteaves, 1903; Stewart, 1927; Murphy and Rodda, 1960) to the solarielline genus *Solariella* Wood, 1842. This is not surprising, given that Hickman and McLean (1990) reported that solariellines are known to have produced convergences with margaritine shells. Fossil species of *Solariella* have been characterized (e.g., Davies, 1971; Kiel and Bandel, 2001) as having a continuous peristome, spiral cords that can be strongly noded, a keel on the base of the shell, and a very prominent spiral cord on the rim of the umbilicus. *Igonoia* differs from *Solariella*

by having a discontinuous peristome, sunken suture, shoulder with raised growth lines with or without axially aligned beads, whorl sides with or without axially aligned beads, and commonly an absence of a very prominent spiral rib bordering the umbilicus.

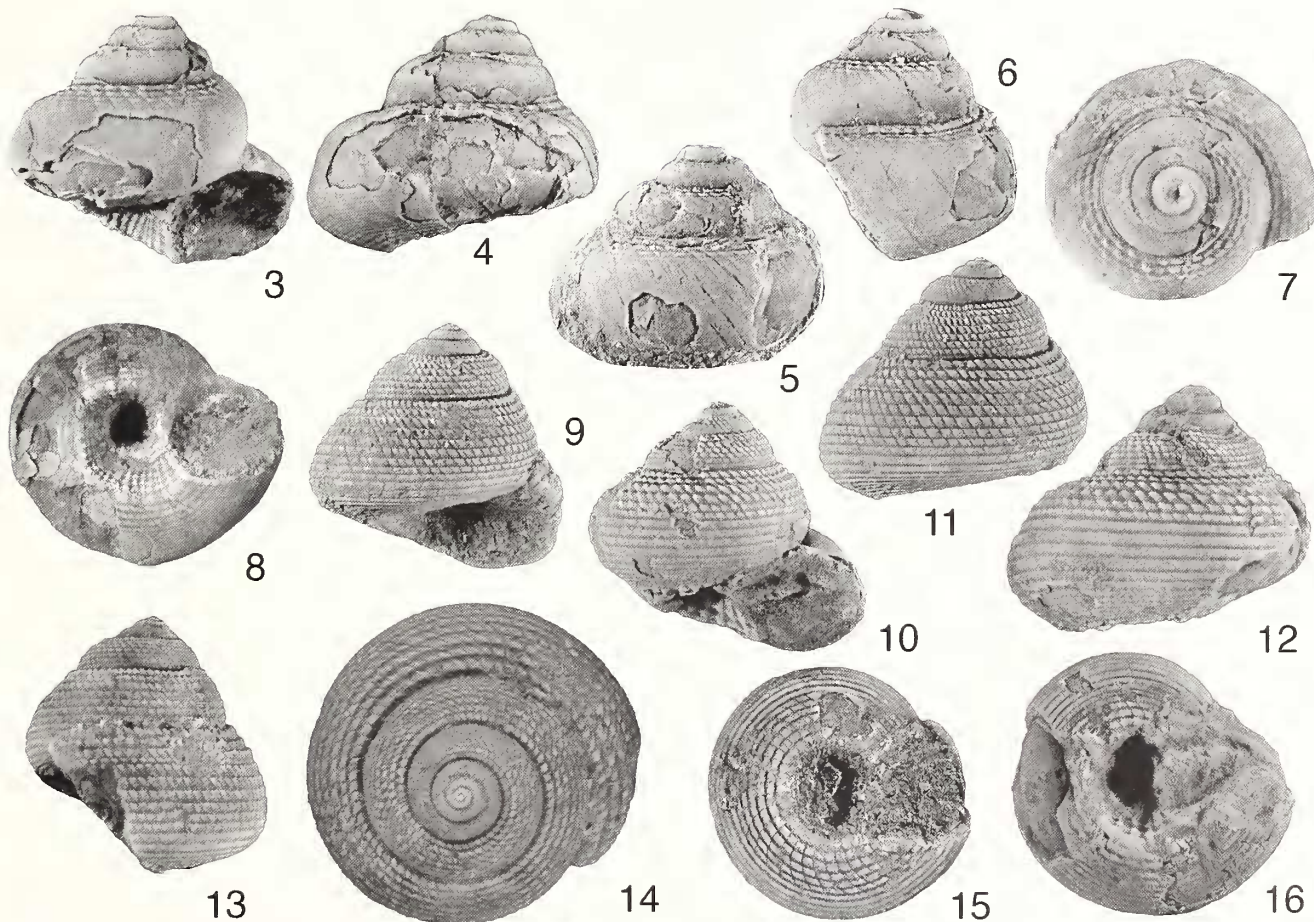
Igonoia is similar to genus *Margarites* J. E. Gray, 1847 (ex Leach ms), but *Igonoia* differs by having a ramp or shoulder with raised growth lines with or without axially aligned beads, whorl sides with or without axially aligned beads, and commonly a less prominent spiral rib bordering the umbilicus.

Igonoia kieli new species

(Figures 3–8)

Diagnosis: Small-sized *Igonoia*, ramp slightly concave, moderately wide, and bearing up to three beaded spiral ribs (posteriormost ones more prominent); whorl sides smooth or with some prominent growth lines present and extending posteriorward across ramp.

Description: Shell size small (up to height 8 mm, diameter 9 mm, same specimen). Shell height



Figures 3–16. Albian species of *Igonoia* new genus. Specimens coated with ammonium chloride. 3–8. *Igonoia kieli* new species. 3–7. Holotype LACMIP 13682, LACMIP loc. 22900, height 8.7 mm, diameter 9.4 mm. 8. Paratype LACMIP 13683, LACMIP loc. 22900, height 6.6 mm, diameter 8.4 mm. 9–16. *Igonoia shastana* new species. 9, 11, 13, 14, 15. Holotype LACMIP 13684, LACMIP loc. 28757, height 6.3 mm, diameter 6.2 mm. 10, 12, 16. Paratype LACMIP 13685, LACMIP loc. 24369, height 7.5 mm, diameter 8.1 mm.

approximately 92% of shell diameter. Trochiform. Phaneromphalous. Spire moderately elevated, approximately 54% of shell height. Pleural angle approximately 87°. Protoconch unknown. Teleoconch approximately five convex whorls. Suture impressed. Ramp slightly concave and moderately wide. Upper spire whorls with two subsutural and equal-strength beaded spiral ribs; penultimate whorl with three beaded spiral ribs, all nearly equal strength. Ornament on last whorl with six spiral ribs, posteriormost two beaded (elongate beads) and equal strength, anteriormost four ribs unbeaded and weaker strength. Ornament on whorl sides obsolete or with some widely spaced, prominent growth lines present and extending posteriorward across ramp. Base demarcated by low angulation. Ornament on base consisting of many closely spaced unbeaded spiral ribs, anteriorward becoming broader and beaded toward umbilicus and producing cancellate ornament. Aperture subcircular. Outer and inner lips thin. Peristome discontinuous. Umbilicus wide, its rim angulate and demarcated by moderately strong and beaded spiral rib. Umbilical wall with stronger cancellate ornament than area immediately posterior to umbilical rim. Growth lines prosocline, tilted 28° from vertical.

Holotype: LACMIP 13682, height 8.7 mm, diameter 9.4 mm.

Paratype: LACMIP 13683, LACMIP loc. 22900.

Type Locality: LACMIP 22900, Bald Hills, Ono area, Shasta County, northern California (Area 3).

Geologic Age: Early late Albian (upper *Oxytropidoceras packardii* ammonite zone).

Distribution: Budden Canyon Formation, Chickabally Mudstone Member, Bald Hills, vicinity of Ono, Shasta County, northern California (Area 3); reworked Albian fossils in lower Turonian Venado Sandstone just south of Sites, Colusa County, northern California (Area 5).

Etymology: Named for Steffen Kiel who has made significant contributions to the study of Cretaceous vetigastropods.

Remarks: The examined material consisted of six specimens: five from loc. 22900 (type locality) and one from loc. 24369. Preservation is generally good. *Igonoia kieli* co-occurs with *I. shastana* new species at locs. 22900 and 24369. Locality 22900 is from the upper part of the Chickabally Mudstone Member, and Murphy (1956: figs. 3–5) plotted this locality (as loc. 2900) on his columnar section and on his geologic maps. On his figure 6, he plotted this locality near the top of the *Oxytropidoceras packardii* ammonite zone, and on the biostratigraphic chart shown by Murphy et al. (1969: fig. 2), it appears that this part of the zone is early late Albian in age.

The single specimen of *I. kieli* from loc. 24369 is from the Venado Sandstone. This member is of early Turonian age and contains reworked Albian fossils (Squires and Saul, 2004).

Igonoia kieli differs from *I. shastana* by slightly larger size, subsutural rib, much less uniform ornament, and obsolete ornament on the sides of the whorls. *Igonoia kieli* is similar to *I. muiri* new species, but *I. kieli* differs by having larger size, subsutural rib much weaker on spire whorls, absence of flat ramp, less angulate shoulder, more spiral ribs on shoulder, and much less prominent growth lines incising the spiral ribs on the shoulder.

***Igonoia shastana* new species**

(Figures 9–16)

Diagnosis: Small-sized *Igonoia*, spiral ribs numerous and uniformly noded except on anterior half of last whorl and on posterior part of base of last whorl.

Description: Shell size small (up to height 7 mm, diameter 8.5 mm, same specimen). Shell height approximately 92% of shell diameter. Trochiform. Phaneromphalous. Spire moderately elevated, approximately 50% of shell height. Pleural angle approximately 84°. Protoconch most likely less than one whorl. Teleoconch approximately 4.5 whorls. Suture impressed. All whorls with rounded sides. Ornament obsolete on two earliest whorls. Ornament on remaining whorls consisting of many closely spaced spiral ribs, beaded except on anterior half of last whorl and on posterior part of base of last whorl. Base demarcated by low angulation. Spiral ribs on base anteriorward becoming wider and bearing beads that become elongate near umbilical rim. Aperture circular. Outer and inner lips thin. Peristome probably discontinuous. Umbilicus wide, its rim angulate and demarcated by spiral rib wider and more strongly beaded than adjacent spiral ribs on base. Umbilical wall cancellate. Area abaxial to umbilical rim with irregularly spaced incised growth lines. Growth lines prosocline, tilted approximately 35° from vertical.

Holotype: LACMIP 13684, height 6.3 mm, diameter 6.2 mm.

Paratype: LACMIP 13685, LACMIP loc. 24369.

Type Locality: LACMIP 28757, Thompson Canyon, Yolo County, northern California (Area 6).

Geologic Age: Early late Albian (upper *Oxytropidoceras packardii* ammonite zone).

Distribution: Budden Canyon Formation, upper Chickabally Mudstone Member, Bald Hills, Ono area, Shasta County, northern California (Area 3); reworked Albian fossils in upper Cenomanian “Antelope” shale (upper part), just south of Sites, Colusa County, northern California (Area 5); and reworked Albian fossils in Turonian Venado Sandstone, Thompson Canyon, north

of Putah Creek, Monticello Dam area, Yolo County, northern California (Area 6).

Etymology: Named for its occurrence in Shasta County, northern California.

Remarks: The examined material consisted of eight specimens: three from USGS loc. M-177 (see Squires and Saul [2004: 500] for locality details); two from LACMIP loc. 22900; two from 24369; and one from 28757 (type locality). Distinction between the protoconch and earliest teleoconch whorl cannot be made because the shell is missing in these areas.

Igonoia shastana co-occurs with *I. kieli* new species at locality 22900 in the upper part of the Chickabally Mudstone Member, and both co-occur as reworked Albian material at loc. 24369 in the Venado Sandstone. The USGS loc. M-177 specimens also represent reworked material but are from the upper part of the "Antelope" shale in beds approximately 23 to 30 m below the base of the overlying Venado Sandstone.

According to the LACMIP records, loc. 28757 is in the Yolo Formation. On Matsumoto's (1960: fig. 9) map, this locality plots near the contact between this formation and the underlying Venado Sandstone. Locality 28757 is most likely located in the Venado Sandstone, thus the specimens are also reworked material.

Igonoia shastana and *I. kieli* are somewhat similar in that their early whorls are smooth and a portion of their last whorl has either diminished or obsolete ornament. *Igonoia shastana* differs from *I. kieli* by slightly smaller size, absence of a subsutural rib, much more uniform ornament, and ornament on the sides of the whorls. No known specimens show intermediate morphology between the two species. Future collecting might reveal such specimens, and, hence, the two species could be shown to be conspecific.

***Igonoia onoensis* new species**

(Figures 17–23)

Sollariella stewarti Murphy and Rodda, 1960: 839 (in part).

Diagnosis: Small-sized *Igonoia*, ramp rounded and covered by four to five spiral ribs bearing prominent beads arranged in rows, whorl sides with weak and unbeaded spiral ribs, and basal ornament strong, including wide umbilical cord.

Description: Shell size small (up to height 7 mm, diameter 7 mm, same specimen), glossy surface. Shell height approximately same as shell diameter. Trochiform. Phaneromphalous. Spire moderately elevated, approximately 56% of shell height. Pleural angle 92°. Protoconch smooth (most likely less than one whorl), transition to teleoconch unclear; first half whorl of shell measures 0.38 mm (380 µm) diameter. Teleoconch approximately five whorls. Earliest teleoconch whorl with two equal-strength spiral threads (one on shoulder and one just anterior to shoulder) and three to four much weaker

spiral threads; after another 180°, weaker spiral ribs disappear but spiral threads (two) on or near shoulder continue and become incipiently beaded. All teleoconch whorls with rounded sides. Suture impressed. Ramp rounded, narrow, and covered by four to five equant spiral ribs bearing prominent elongate beads arranged in rows. Ornament on whorl sides consisting of weak (rarely obsolete) unbeaded spiral ribs. Aperture subcircular. Outer and inner lips thin. Peristome probably discontinuous. Base ornamented with several strong, moderately narrow spiral ribs. Umbilicus wide, its rim angulate and demarcated by nodulose wide spiral rib. Area abaxial to umbilical rim with irregularly spaced incised growth lines. Growth lines prosocline, tilted 35° from vertical.

Holotype: LACMIP 13686, height 7.2 mm, diameter 7.2 mm.

Paratype: LACMIP 13687, LACMIP loc. 23476.

Type Locality: LACMIP 23476, Bald Hills, Shasta County, northern California (Area 3).

Geologic Age: Late Cenomanian (slightly older than *Igonoia stewarti*).

Distribution: Budden Canyon Formation, Bald Hills Member, Bald Hills, Ono area, Shasta County, northern California (Area 3).

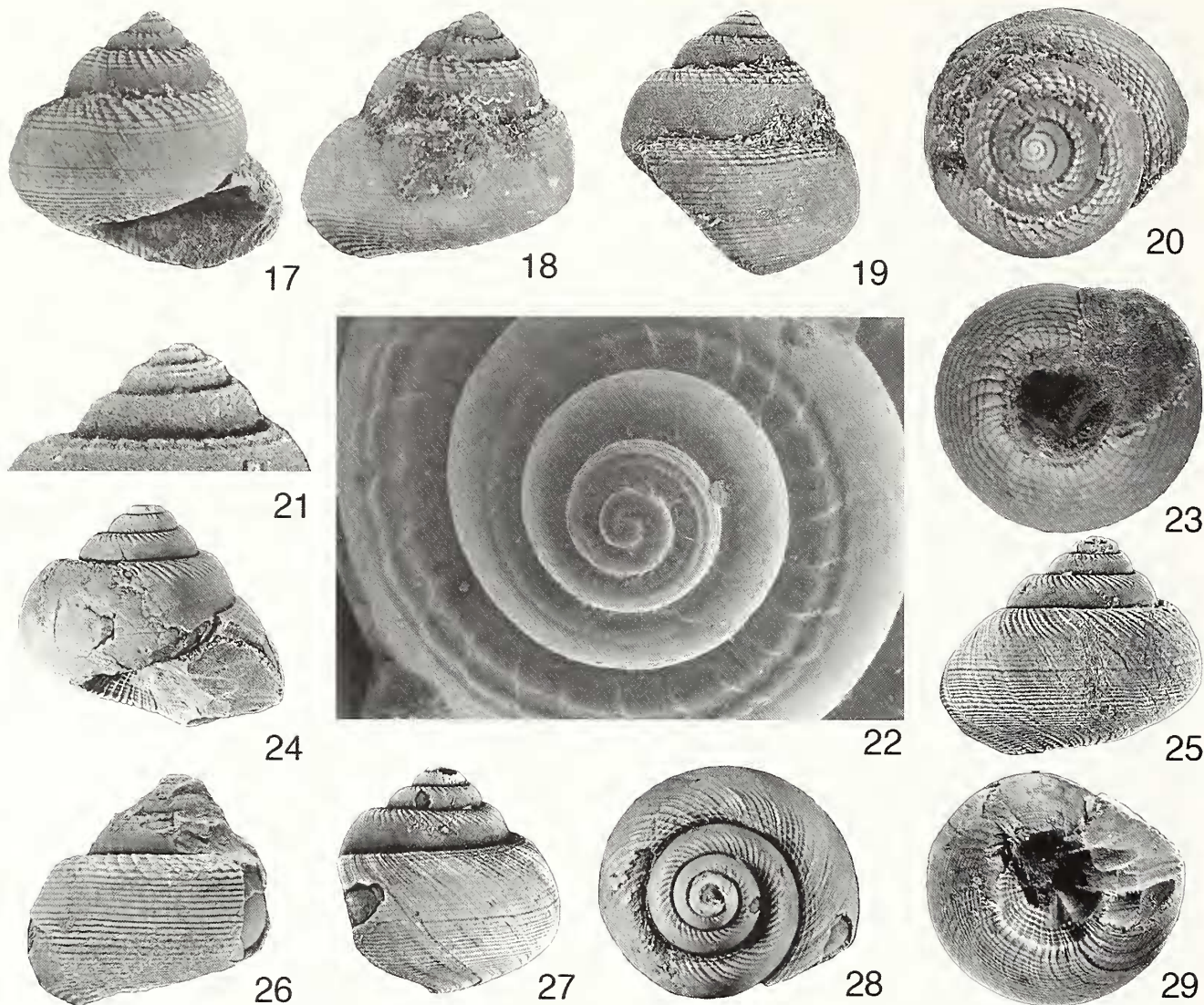
Etymology: Named for the town of Ono, Shasta County, California.

Remarks: Examined material consisted of four specimens (one early? adult and three juveniles), all from LACMIP loc. 23476 in the middle part of the Bald Hills Formation. One of the juveniles has its protoconch intact (Figures 21–22). Murphy and Rodda (1960) did not recognize that the specimens they identified as *S. stewarti* from LACMIP loc. 23476 represent a different species than *S. stewarti*. Although both species occur in the Bald Hills Member, *S. onoensis* is found slightly downsection from *S. stewarti*.

Murphy and Rodda (1960: fig. 2) reported that the aporrhaid gastropod *Arrhoges (Latiala) californicus* (Gabb, 1864) occurs at LACMIP loc. 23476. Popenoc (1983) assigned this aporrhaid a Cenomanian? to early Turonian age.

The new species is similar to *Igonoia stewarti* but *I. onoensis* is characterized by having prominently beaded spiral ornament, whereas *I. stewarti* is characterized by having weaker ornament consisting of raised growth lines. In addition, *I. onoensis* differs by having smaller size, more sloped ramp, beaded spiral ribs on the ramp, nearly obsolete spiral ribs on sides of the whorls, and slightly stronger ornament on the base.

The new species most resembles *Igonoia muii* new species but differs by having a larger size, no subsutural cord, rounded shoulder (rather than angulate), and shoulder demarcated by several equal-strength spiral ribs, rather than by only two spirals, with the posteriormost



Figures 17–29. Cenomanian species of *Igonoia* new genus. Specimens coated with ammonium chloride. **17–23.** *Igonoia oncoensis* new species. **17, 18, 19, 20, 23.** Holotype LACMIP 13686, LACMIP loc. 23476, height 7.2 mm, diameter 7.2 mm. **21–22.** Paratype LACMIP 13687, LACMIP loc. 23476, height 3 mm, diameter 4.5 mm. **21.** Abapertural view of spire tip. **22.** SEM image of left-lateral view of protoconch and early teleoconch whorls, width of view 2.5 mm. **24–29.** *Igonoia stewarti* (Murphy and Rodda, 1960). **24, 25, 27, 28, 29.** Holotype LACMIP 9821, LACMIP loc. 23763, height 8 mm, diameter 8.9 mm. **26.** Hypotype LACMIP 13688, LACMIP loc. 23465, height 6.2 mm, diameter 6.9 mm.

the strongest. In addition, on *I. oncoensis*, the ornament on the base is not as weak abaxially.

***Igonoia stewarti* (Murphy and Rodda, 1960) new combination**
(Figures 24–29)

Solariella stewarti Murphy and Rodda, 1960: 839 (in part), pl. 103, figs. 4–5.

Diagnosis: Small-sized *Igonoia* with spire low, shoulder rounded with numerous very fine to fine spiral ribs crossed by prominently raised growth lines, basal ornament weak, and umbilical cord moderately strong.

Description: Shell size small (up to height 8 mm, diameter 9.2 mm, same specimen), glossy surface. Shell height approximately 89% of shell diameter. Troehiform. Phaneromphalous. Spire low, approximately 45% of shell height. Pleural angle 92° . Protoconch unknown. Teleoconch approximately six whorls, all with rounded sides. Suture nearly eanalieulated. Shoulder rounded with three to five spiral ribs (noded), commonly very weak to weak. Spiral ornament elsewhere (on sides of whorls) consisting of numerous and closely spaced, weak to rarely moderately strong spiral riblets with tendency to being faint to obsolete. Shoulder with numerous and closely spaced, weak to moderately strong ribs coincident with

prominently raised growth lines. Aperture subcircular. Outer and inner lips thin. Peristome probably discontinuous. Base ornamented by numerous, very weak spiral riblets. Umbilicus rim angulate and demarcated by somewhat nodulose, moderately strong to strong spiral rib. Area just posterior to umbilical rim with irregularly spaced ribs. Area just abaxial to umbilical rim cancellate on some specimens. Umbilical wall cancellate. Growth lines prosocline, tilted 35° from vertical.

Holotype: LACMIP 9821 [= UCLA 28622], height 8 mm, diameter 8.9 mm.

Paratype: LACMIP 9822 (unfigured here) [= UCLA 28683], LACMIP loc. 23763.

Type Locality: LACMIP 23763, Bald Hills, Shasta County, northern California (Area 3).

Geologic Age: Late Cenomanian (slightly younger than *I. onoensis*).

Distribution: Budden Canyon Formation, Bald Hills Member, Bald Hills, Ono area, Shasta County, northern California (Area 3).

Remarks: The examined material consisted of nine specimens: four from LACMIP loc. 23464, three from LACMIP loc. 23465, and five from LACMIP loc. 23763. Preservation is good. Two of the specimens from LACMIP locality 23465 have stronger spiral ribs than normal for this species, and one of these specimens is illustrated in Figure 26. These variants were not mentioned by Murphy and Rodda (1960).

Murphy and Rodda (1960: 839) believed that *S. stewarti* is represented by some of the type material of *Igonoia angulata*. During this present investigation, this latter material was studied and found to consist of two species: *I. angulata* (Gabb) and *I. muiri* new species. The latter species does resemble *I. stewarti* (see *I. muiri* for a comparison).

Murphy and Rodda (1960) did not recognize that the specimens they identified as *Solariella stewarti* from LACMIP loc. 23476 represent a different species. In this present report, these specimens are identified as *Igonoia onoensis* new species, which is found in the middle part of the Bald Hills Member of the Budden Canyon Formation.

Igonoia stewarti is present in the upper half of the Bald Hills Member of the Budden Canyon Formation (Murphy and Rodda, 1960: 839, text-fig. 2). The associated macrofauna, especially the species of the gastropods *Gyrodos greeni* Murphy and Rodda, 1960 and *Gyrodos allisoni* Murphy and Rodda, 1960, are indicative of a late Cenomanian age (Popenoe et al., 1987: fig. 1). Murphy and Rodda (1960: fig. 2) also reported that the ammonite *Desmoceras (Pseudouhligella)* cf. *barryae* was found with *S. stewarti* at LACMIP loc. 23464, and Matsumoto (1959: 7) reported that this ammonite “seems to occur in the Cenomanian.” Murphy and Rodda (1960) reported the ammonite *Turrilites*

dilleri from loc. 23464. Rodda (1959) assigned this ammonite a Cenomanian age. Murphy and Rodda (1960) also reported that *S. stewarti* is also present in the “formation” that overlies the Bald Hills “formation.” Using the revised stratigraphy of Murphy et al. (1969), this overlying “formation” is the Gas Point Member (Cenomanian to Turonian) of the Budden Canyon Formation. The present author, however, was unable to confirm a Gas Point Member occurrence of *I. stewarti*.

***Igonoia vacca* new species**

(Figures 30–34)

Diagnosis: Small-sized *Igonoia* with spire low and teleoconch bearing widely spaced, narrow spiral ribs crossed by widely spaced and raised growth lines, especially on rounded shoulder.

Description: Shell size small (up to height 7 mm, diameter 8 mm, same specimen). Shell height slightly less or approximately same size as shell diameter. Trochiform. Phaneromphalous. Spire low, approximately 46% of shell height. Pleural angle 85°. Protoconch unknown. Teleoconch approximately six convex whorls. Suture impressed; sutural area flattish on penultimate whorl. Teleoconch approximately four convex whorls. Shoulder area rounded. Ornament consisting of widely spaced, narrow spiral ribs; spire whorls with five riblets; spiral ribs on last whorl somewhat clustered together: two near suture, one on shoulder, four to five on sides of whorls, and numerous ones on base. Spiral ribs on base gradually become slightly stronger near umbilical rim where raised growth lines cross spiral ornament. Aperture circular. Outer and inner lips thin. Peristome discontinuous. Umbilicus moderately wide, its rim angulate and demarcated by beaded spiral cord with beads grading into nodes toward anterior end of columella. Umbilical wall cancellate. Growth lines prosocline, tilted 30° from vertical.

Holotype: LACMIP 13689, height 5.6 mm, diameter 6.6 mm.

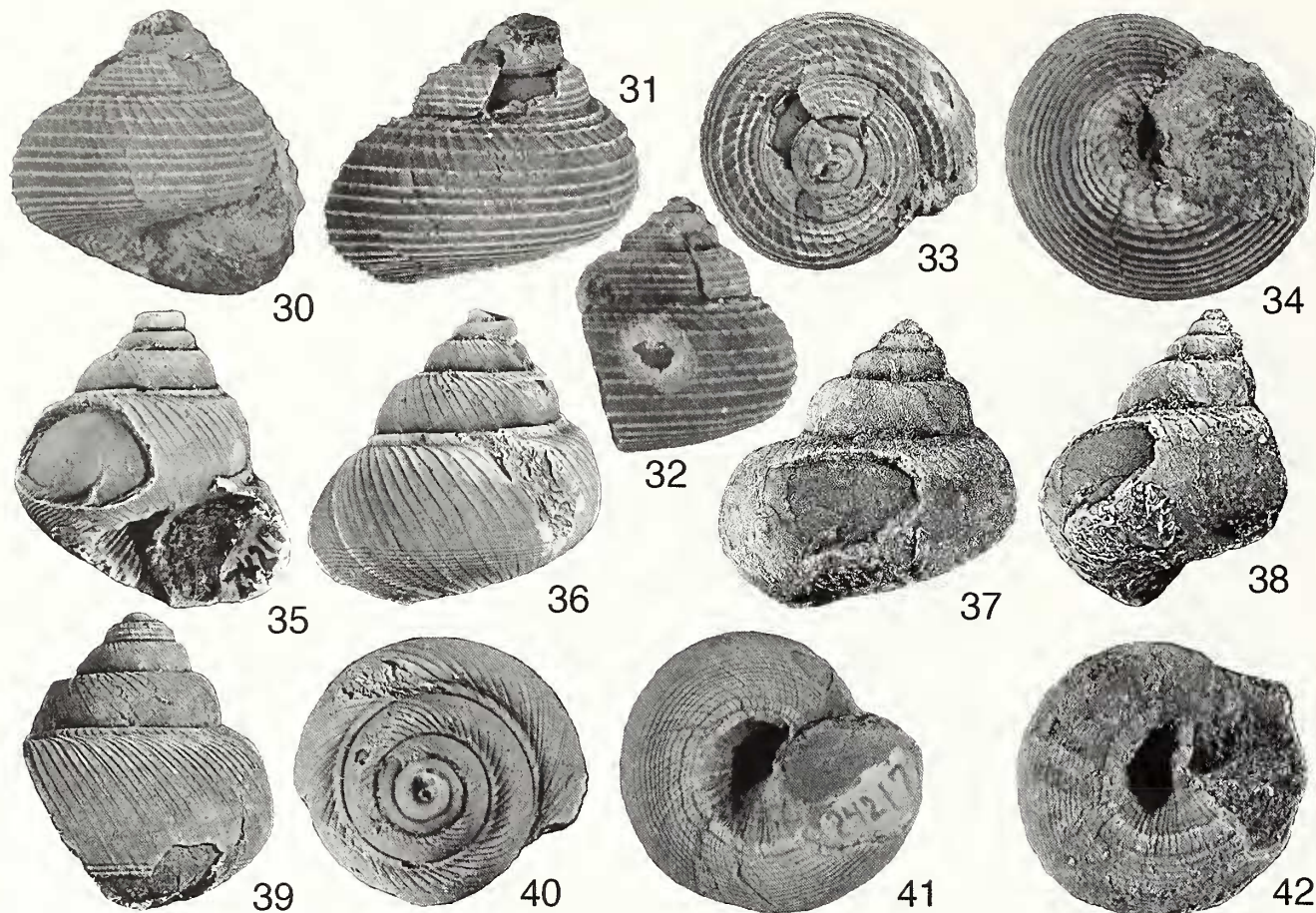
Type Locality: LACMIP 25421, east of Redding, Shasta County, northern California (Area 2).

Geologic Age: Late Turonian.

Distribution: Redding Formation, Melton Sandstone Member, east of Redding, Shasta County, northern California (Area 2); Ladd Formation, Baker Canyon Member, Santa Ana Mountains, Orange County, southern California (Area 8).

Etymology: Named for its occurrence in the Cow Creek area east of Redding, Shasta County, northern California; *vacca*, Latin, meaning cow, used as a noun in apposition.

Remarks: The examined material consisted of 17 specimens, and nearly all of them are from the Redding



Figures 30–41. Late Turonian and late Santonian species of *Igonioia* new genus. Specimens coated with ammonium chloride. **30–34.** Late Turonian *Igonioia vacca* new species, holotype LACMIP 13689, LACMIP loc. 25421, height 5.6 mm, diameter 5.6 mm. **35–42.** Late Santonian *Igonioia occidentalis* (Whiteaves, 1903). All specimens coated with ammonium chloride. **35, 36, 40.** Hypotype LACMIP 13690, LACMIP loc. 24217, height 8.7 mm, diameter 7 mm. **37–38.** Paratype GSC 5918a, Nanaimo area, Vancouver Island, British Columbia, height 5.5 mm, diameter 7.1 mm. **38.** Left-lateral view. **39.** Hypotype LACMIP 13691, LACMIP loc. 10794, height 7 mm, diameter 6.6 mm. **41.** Hypotype LACMIP 13692, LACMIP loc. 24217, diameter 10 mm. **42.** Paratype GSC 5919, Nanaimo area, Vancouver Island, British Columbia, diameter 6.9 mm, x5.4.

Formation. Most of the specimens have good preservation. The new species somewhat resembles *Igonioia shastana* new species, but the former differs by having non-beaded spiral ribs and narrower and much more widely spaced ribs.

***Igonioia occidentalis* (Whiteaves, 1903) new combination**

(Figures 35–42)

Solariella (radiatula ? var.) *occidentalis* Whiteaves, 1903: 368–369, pl. 45, figs. 5, 5a.
Solariella roddai Saul, 1959.

Diagnosis: Moderately small-sized *Igonioia* with shell height greater than shell diameter, commonly with prominent subsutural cord, and raised growth lines stronger than nearly obsolete spiral ribs, except on base, on subsutural spiral cord, and on umbilical rim.

Description: Shell size moderately small (up to height 13 mm (estimated), diameter 12 mm, same specimen). Shell height approximately 15% greater than shell diameter. Trochiform. Phaneromphalous. Spire moderately high, approximately 59% of shell height. Pleural angle approximately 81°. Protoconch unknown. Teleoconch approximately five to six whorls, all with rounded sides. Suture impressed, rimed by prominent, unmoded subsutural cord. Shoulder narrow. Ornament generally weak and crossed by raised growth lines. Upper spire whorls with cancellate ornament. Lower spire whorls with many wide-spaced, flat ribs separated by finely incised lines. Last whorl similar to lower spire whorls, except for base with many weak and closely spaced spiral ribs that become slightly stronger anteriorward. Aperture circular. Outer lip thin, inner lip thicker and projecting slightly out over umbilicus. Peristome discontinuous. Umbilicus moderately wide, its rim angulate and demarcated by spiral rib, weakly beaded with beads

decreasing in strength anteriorward. Base of last whorl near umbilical rim and umbilical wall cancellate. Growth lines prosocline, tilted 30° from vertical.

Holotype: GSC 5918, height 4.7 mm, diameter 6.9 mm.

Paratypes: GSC 5918a, 5918b, 5919, 5919a, all from the type locality.

Type Locality: Vicinity of Nanaimo, Vancouver Island, British Columbia (Area 1).

Geologic Age: Santonian.

Distribution: LOWER SANTONIAN: Haslam Formation, Benson Creek and Nanaimo River, both in the vicinity of Nanaimo, Vancouver Island, British Columbia (Area 1); Redding Formation, upper Member V, Clover Creek, east of Redding, Shasta County, northern California (Area 2). UPPER SANTONIAN: Redding Formation, Member VI, Clover Creek, east of Redding, Shasta County, northern California (Area 2); tentative occurrence in Chico Formation, top of Musty Buck Member, Chico Creek, Butte County, northern California (Area 4).

Remarks: Examined material consisted of 212 specimens, which represents just over 80% of the known studied specimens of *Igonoia*. Preservation is moderately good. Whiteaves (1903) reported that some of his type material was collected (by others) from Brennan Creek in the vicinity of Nanaimo, Vancouver Island. According to R. Graham (person. commun.), it should read Benson Creek. *Igonoia occidentalis* is most abundant in lower Santonian rocks at LACMIP loc. 24246 (Area 2), where 168 specimens have been collected. A few weathered specimens tentatively identified as this new species are from the top of the Musty Buck Member in the Chico Formation, Butte County, northern California.

Igonoia occidentalis is similar to *Igonoia angulata* but differs from the latter by much larger shell size, suture not canaliculate, presence of subsutural rib, and raised growth lines extending from suture to suture on spire whorls and from suture to umbilical rim on last whorl. *Igonoia occidentalis* resembles the Upper Cretaceous margaritine *Atrina ornatissima* (Gabb, 1864) from California but differs from the latter by having shell height greater than shell diameter, subsutural cord, non-sloping ramp, more prominent growth lines, inner lip not projected over edge of umbilicus, and umbilical rim demarcated by an angulation rather than a prominent spiral rib.

Stoliczka (1867–1868) reported *Solariella radiatula* Forbes, 1846, from southern India at the locale of Odiyam [= Odiium of old usage], which, according to Sundaram et al. (2001), is stratigraphically situated in the upper Albian to Cenomanian Karai Formation. Although Whiteaves (1903) questionably identified *I. occidentalis* as *Solariella (radiatula ? var.) occidentalis*, this species is here identified as *I. occidentalis* because it is not Forbes's species *radiatula*.

***Igonoia angulata* (Gabb, 1869) new combination**
(Figures 43–47)

Margaritella angulata Gabb, 1869: 172 [in part], pl. 28, figs. 55.
Solariella angulata (Gabb). Stewart, 1927: 317, pl. 24, fig. 17.

Diagnosis: Very small-sized *Igonoia* with suture canaliculate, ornament prominent only on shoulder, prominently raised growth lines on periphery and on base of last whorl.

Description: Shell size very small (up to height 4.5 mm (estimated), diameter 4.8 mm, same specimen). Shell height approximately same as shell diameter. Trochiform. Phaneromphalous. Spire moderately high, approximately 54% of shell height. Pleural angle 80°. Protoconch unknown. Teleoconch approximately four whorls. Suture canaliculate. All whorls with flattish sides. Shoulder angulate, crossed by many prominently raised growth lines that become obsolete near middle portion of whorls. Spiral ornament obsolete on spire whorls; spiral ornament on last whorl consisting of many very fine threads starting at middle portion of whorls and continuing onto base. Base demarcated by rounded angulation; base covered by many very fine spiral threads that become microscopically beaded anteriorward. Aperture elliptical. Outer and inner lips thin. Peristome probably discontinuous. Umbilicus rim angulate and demarcated by beaded spiral ribs. Growth lines prosocline, tilted approximately 33° from vertical.

Lectotype: ANSP 4238 (designated by Stewart (1927) but missing since 1992 (P. Colloman, person. commun.), height 4.4 mm, diameter 5 mm.

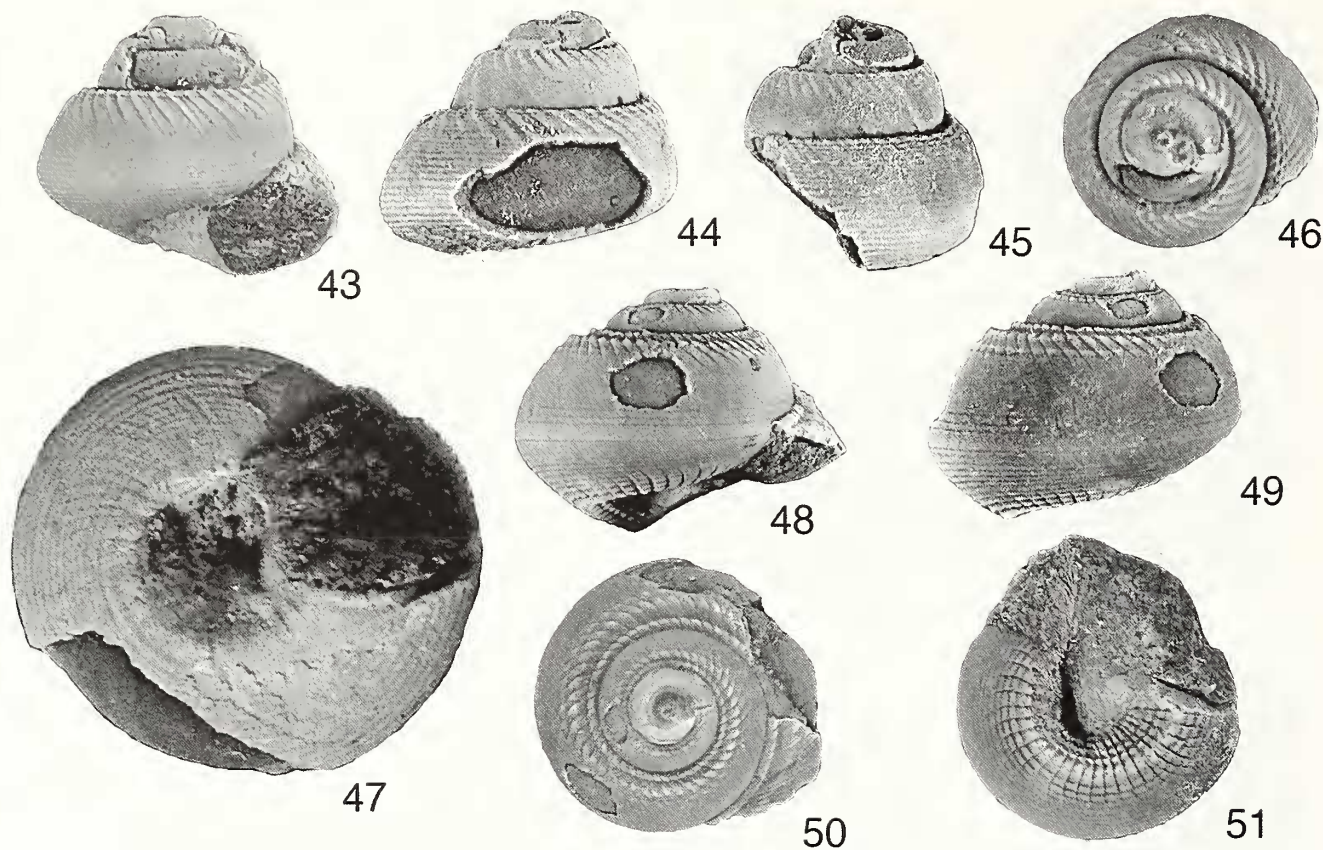
Paralectotypes: ANSP 79512 [ex-ANSP 4238].

Type Locality: LACMIP 23312, Franklin County, near Martinez, Contra Costa County, northern California (Area 7).

Geologic Age: “Mid” Maastrichtian (late early to middle late).

Distribution: Panoche Formation, Franklin Canyon, southwest side of Martinez, Contra Costa County, northern California (Area 7).

Remarks: The examined material consisted of two specimens, both previously part of a supposed group of six ANSP paralectotypes of *Solariella angulata*. Five of these specimens are stored together as ANSP 79512 [ex 4238] and the sixth one is ANSP 79153. Of the five ANSP 79512 specimens, only two are like the drawing provided by Gabb (1869) and the photograph provided by Stewart (1927) of the lectotype of *S. angulata*. Of the remaining three specimens, two belong to *Igonoia muiri* new species, and one is an indeterminate species because it has lost most of its shell. The ANSP 79153 specimen is a badly crushed naticid? gastropod, and the



Figures 43–51. Maastrichtian species of *Igonioia* new genus. **43–47.** *Igonioia angulata* (Gabb, 1869), paralectotype ANSP 79512 [ex 423S], LACMIP loc. 23312, height 4.4 mm, diameter 5 mm. **48–51.** *Igonioia muiri* new species, holotype ANSP 81350, LACMIP loc. 23312, height 5.2 mm, diameter 7 mm.

rock matrix filling its aperture is light in color, soft, and totally unlike the blackish-gray, well-cemented siltstone in the apertures of the two specimens of *I. angulata* and the two specimens of *I. muiri*.

Gabb (1869) reported that the type locality of his *S. angulata* to be “at Martinez.” He did not collect the type specimens; they were sent to him by a collector. The area immediately surrounding this city has stratigraphic units ranging in age from Late Cretaceous to Miocene, and there are several faults (Weaver, 1953). The location of the type locality of *I. angulata*, therefore, has been poorly known; subsequently, the geologic age of this species has been uncertain. Inspection (by the present author) of the rock type associated with the two specimens of *I. angulata* revealed a match with the rock type associated with the gastropod *Atira inornata* (Gabb, 1864), which is also found at LACMIP loc. 23312. Squires (2010) reported that *A. inornata* is of “mid” Maastrichtian age. According to the LACMIP records, this locality is the same as Gabb’s original “at Martinez” Cretaceous locality. On Dibblee’s (1980) geologic map of the area, this locality plots in the Panoche Formation.

Cossmann (1918: 257) based the earliest record of genus *Periailax* Cossmann, 1888, on “*Margaritella angulata* Gabb, 1869 from the so-called “Chico Group”

at Martinez, California. He assigned these strata to the “Aturian,” which according to Harland et al. (1982: 110), generally refers to the Campanian.

***Igonioia muiri* new species**
(Figures 48–51)

Margaritella angulata Gabb, 1869: 172 [in part].

Solariella angulata (Gabb). Stewart, 1927: 317 [in part].

Diagnosis: Very small-sized *Igonioia* with spire low, beaded subsutural rib, ramp flat, shoulder angulate and bearing two spiral ribs (beaded), subsutural area and ramp incised by prominently raised growth lines, and sides of whorls smooth.

Description: Shell size very small (up to height 5 mm (estimated), diameter 7 mm, same specimen). Shell height approximately 90% of shell diameter. Trochiform. Phaneromphalous. Spire low, approximately 43% of shell height. Pleural angle approximately 95°. Protoconch unknown. Teleoconch approximately four whorls. Suture impressed, bordered by prominent subsutural beaded rib. Ramp flat. Spire whorls with sides somewhat rounded; last whorl with sides flattish. Ornament on whorls consisting of beaded subsutural rib, stronger

beaded spiral rib on angulate shoulder, and one other spiral rib (weaker) just anterior to shoulder; all three ribs incised by moderately widely spaced prominently raised growth lines that become obsolete on middle portion of sides of whorls. Base demarcated by rounded angulation; several weak spiral threads posterior to angulation. Ornament on base consisting of many spiral ribs becoming stronger and beaded anteriorward; beads crossed by prominent growth lines, thereby producing cancellate ornament. Aperture elliptical. Outer and inner lips thin. Peristome discontinuous. Umbilicus wide, its rim angulate and demarcated by prominently beaded spiral rib. Umbilical wall cancellate. Growth lines prosocline, tilted 42° from vertical.

Holotype: ANSP 81350, height 5.2 mm, diameter 7 mm.

Paratype: ANSP 81351 (unfigured), from the type locality.

Type Locality: LACMIP 23312, Franklin County, near Martinez, Contra Costa County, northern California (Area 7).

Geologic Age: "Mid" Maastrichtian (late early to middle late).

Distribution: Panoche Formation, Franklin Canyon, southwest side of Martinez, Contra Costa County, northern California (Area 7).

Etymology: Named for John Muir, early Californian naturalist and visionary conservationist, whose home is in the immediate vicinity of the type locality of the new species.

Remarks: The examined material consisted of two specimens, previously part of a supposed group of six paralectotypes of *Solariella angulata* (see "Remarks" for *I. angulata*).

The new species occurs with *I. angulata* at LACMIP loc. 23312, which occurs in strata of "mid" Maastrichtian age (see "Remarks" for *I. angulata*). The new species differs from *I. angulata* by larger size, wider shell, non-annulate suture, subsutural rib, two spiral (beaded) ribs on shoulder, and much stronger spiral ribs on base.

Igonoia muiri is most similar to *I. onocensis* new species but differs from the latter by having smaller size, subsutural cord, angulate shoulder (rather than rounded), shoulder demarcated by only two spirals, with the posteriormost the strongest (rather than with approximately seven spirals, all nearly equal in strength), ornament on base less well developed, and ornament on base somewhat obsolete near middle portion of sides of whorls.

PALEOGEOGRAPHIC AND PALEOCLIMATIC COMMENTS

Igonoia kieli and *I. shastana*, the earliest known representatives of this new genus, existed in the Albian, which, according to Hallam (1992: fig. 4.8) and Frakes (1999), was a time of warming ocean waters and a pronounced sea-level rise. During the Albian and Cenomanian, *Igonoia* reached its peak diversity (two species during each stage) in northern California. There was exceptional warming during the Turonian, as well as one of the highest sea-level stands of the entire Cretaceous (Haq et al., 1987; Frakes, 1999). These conditions would have been ideal for *I. vacca* to become widespread in the study area, but the number of specimens is low. In addition to being found in northern California (i.e., approximately 42° N) (Area 2), *I. vacca* also ranged as far south as the Santa Ana Mountains in southern California (Area 8). Based on an analysis of paleomagnetic studies (Dickerson and Butler, 1998: fig. 1), the Santa Ana Mountains are part of a microplate tectonic terrane that would have been even slightly farther south (approximately 32° N, compared to its present-day location at 33° N). Based on volutodermine and opine bivalve studies (Saul and Squires, 2008; Squires and Saul, 2009), warm-temperate surface waters were the norm for the study area and the approximate position of the Late Cretaceous subtropical/warm-temperate boundary shifted from 43° N in the Turonian to 36° N in the Campanian and Maastrichtian.

During the latest Turonian to Coniacian there was marked cooling (Frakes, 1999) and a drastic drop in sea level (Hallam, 1992). No Coniacian specimens of *Igonoia* are known. Relative to the Coniacian, there was some warming during the Santonian and early part of the Campanian (Frakes, 1999), and sea level remained generally high (Hallam, 1992). The time of greatest abundance of *Igonoia* specimens was the Santonian, with most of the specimens found in northern California. The occurrence of *I. occidentalis* in the Nanaimo Group on Vancouver Island, British Columbia (Area 1) is an artifact of tectonic transport. Work on Cretaceous mollusks by Squires and Saul (2006: 86) and Saul and Squires (2008: 214) supported the contention that the Nanaimo Group was deposited not any farther south than northern California.

No Campanian age specimens of *Igonoia* are known, and the only study area specimens of *Igonoia* Maastrichtian age are two specimens each of *I. angulata* and *I. muiri*.

In summary, the localities of *Igonoia* are mainly clustered around the 40° N latitude in northern California (Figure 1), thus they plot within the warm-temperate water regime (see Saul and Squires, 2008: fig. 3). Prior to tectonic transport complications, study area *Igonoia* were most widespread, but few in number, during the relatively warm time of the Turonian when temperate waters expanded latitudinally. The highest abundance of specimens, however, was during the Santonian,

which was a cooler time relative to the Turonian. The lack of Campanian-age *Igonoia* and the paucity of Maastrichtian-age specimens are very puzzling, and the reasons await further study.

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22893. Dark brown sandstone, 5260 ft. S 28.5° W of intersection of Ono-Igo Road and Cottonwood-Igo Road, on East Fork of Hulen Creek, Ono Quadrangle (15 minute), Bald Hills, Ono area, Shasta County, California. Budden Canyon Formation, Huling Sandstone Member. Age: Late Aptian. Collector: M. A. Murphy, January 1, 1951.
22900. 1500 ft. N18°W of confluence of North Fork of Cottonwood Creek and Huling Creek; on Huling Creek, in conglomeratic sandstone forming the narrows; is first sandstone below junction with east fork of Huling Creek, NE/4 of sec. 17, T. 30N, R. 6W, Ono Quadrangle (15-minute, 1952), Bald Hills area, Shasta County, California. Budden Canyon Formation, Chickabally Mudstone Member. Age: Early late Albian (upper part of *Oxytropidoceras packardi* ammonite zone). Collector: M. A. Murphy, January, 1953.
23312. Crest of 500 ft. ridge on N side of Franklin Canyon due W of the old John Muir place at S end of city of Martinez, northeastern corner of Briones Valley Quadrangle (7.5 minute, 1959), Contra Costa County, California (= Gabb's original Martinez Cretaceous locality). Great Valley Sequence. Age: "Mid" Maastrichtian (late early to middle late). Collector: W. P. Popenoe, August, 1944.
23476. Hard concretionary sandstone, 3000 ft. S of NW corner of sec. 30, T. 30 N, R. 6 W, Ono Quadrangle (15 minute), Coyote Creek, Bald Hills, Ono area, Shasta County, California. Budden Canyon Formation, Bald Hills Member. Age: Cenomanian. Collector: P. U. Rodda, August, 1955.
23896. Hard concretionary sandstone in gully bottom and on slope to the west, 570 ft. W and 2300 ft. S of NE corner of sec. 25, T. 31 N, R. 6 W, Redding Quadrangle (7.5 minute, 1957, photorevised 1969), Clear Creek area, Shasta County, northern California. Budden Canyon Formation, Chickabally Mudstone Member. Age: Late early Albian (*Breweriaceras hulense* ammonite zone). Collectors: P. U. Rodda, M. A. Murphy, and W. P. Popenoe, August, 1955.
24246. Sandstone bed 30–40 ft. stratigraphically above conglomerate at center of W line of sec. 33, on N side of divide between Clover and Basin Hollow creeks, Shasta County, northern California. Redding Formation, upper Member V. Age: Early Santonian. Collector: W. P. Popenoe, August 25, 1959.
25421. Sandstone nodules in shale, left bank of Little Cow Creek, about 5 ft. above the channel bottom, 75 m NE (upstream) from intersection of the creek bed with the line fence, S line of sec. 9, T. 32 N, R. 3 W, Millville Quadrangle (15-minute, 1953), Shasta County, California. Formation: Redding Formation, Melton Sandstone Member. Age: Late Turonian. Collector: W. P. Popenoe, summer 1937.
28757. 2700 ft. N of Putah Creek, section 20, T. 8 N, R. 2 W, Thompson Canyon, just NE of Monticello Dam (forming Lake Berryessa), near the letter "y" in the word "Canyon," Monticello Dam Quadrangle (7.5 minute, 1959), Yolo County, Venado Sandstone (containing reworked Albian fossils). Age: Turonian (see Matsumoto, 1960: 38).

APPENDIX 1. TYPE LOCALITIES OF THE NEW SPECIES

Localities are LACMIP. All quadrangle maps listed below are U. S. Geological Survey maps.

Detailed information about the other cited localities in the text is available via the following: LACMIP website: <http://ip.nlm.org/ipdatabase/locality_show>; UCMP website: <<http://ucmpdb.Berkeley.edu/loc.html>>.